Enhancing Building Performance Through More Responsive Maintenance System

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Abstract:
Previous studies have applied different techniques and concepts to planning, designing and executing construction projects. However, few studies have been conducted in maintaining such projects. Maintaining and operating any constructed facility costs more than its initial cost. The aim of this study is to improve maintenance processes by simulating the concept of multi-skilled technician to an existing maintenance process. Statistical data and maintenance process map of Saudi Consolidated Electric Company (SCECO) are modeled in Extend+BPR® to be an experimental tool for evaluating the benefits of multi-skilled technicians. The simulation models of this study showed significant improvement in both preventive and corrective maintenance processes.

Keywords:
preventive, corrective, maintenance, simulation, MST

1. Introduction

One way to save cost and add value to an organization is to improve its maintenance system. In the Kingdom of Saudi Arabia, a high percentage of the government's expenditure has been directed toward maintenance and operation projects (Al-Arjani 2002). Therefore, any reduction in resources applied to building maintenance will be reflected on the national economy (Horner *et al.* 1997). There are many actions in reducing maintenance cost (e.g., process redesign/reengineering, better utilization of resources, reducing errors and reworks, … etc). This study aims at reducing cost of maintenance work orders by employing multi skilled technicians. The concept of multi skilled technician (MST) refers to a labor utilization strategy in which workers learn more multiple skills in one or more trades outside their primary trade (Carley *et al.* 20003).

Manpower plays a significant role on the quality of maintenance. This is because the costs of maintenance labor constitute the largest block in the maintenance costs (Mjema 2002). Therefore, enhancing labor performance will add value to the whole maintenance process. One way to enhance labor performance is to employ the concept of MST. This has proven its success in the manufacturing industry where it could be applicable to the building industry.

The concept of MST implies that a technician can perform more than one work order (WO) of different services (e.g., mechanical, electrical, and so forth). For example, installing a water heater needs a plumber and electrician to complete the job in a traditional maintenance system. With MST principle, this work order can be done by one technician instead of two. In this way work orders will wait less time in the maintenance system, thus increasing the throughput and enhancing the availability of a facility. Thus, the objective of this study is to assess the potentiality of employing multi-skilled technicians to an existing maintenance process using computer simulation.

Employing the concept of MST has numerous advantages which include: overcoming labor shortage (Lobo and Wilkinson 2008), responding to unexpected events without consulting a supervisor (Carley *et al.* 2003), improving quality (Carley *et al.* 2003), enhancing process flexibility (Organ *et al*. 1998), reducing cost (Carley *et al.* 2003 and Pintelon *et al*. 2006), and increasing productivity (Oral *et al.* 2003 and Pintelon *et al*. 2006).

Several researchers modeled maintenance processes to evaluate certain issues. The simulation models of Ip *et al.* (2000) and Mjema (2002) focused mainly on capacity planning in order to determine the appropriate number of the maintenance personnel. Duffuaa *et al.* (2001) developed a generic conceptual simulation model that consisted of seven modules, such as materials and spares supply. The modules of Duffuaa's model are designed to fit common maintenance system requirements but not for specific issues like MST. Wang and Hwang (2004) integrated qualitative method in their mathematical model to include human factors (e.g., human errors) to find the optimum balance between the costs and benefits of maintenance. This study incorporates another qualitative factor, which is MST, in quantitative simulation models. The concept of MST and its impact on building maintenance was not thoroughly discussed in previous studies.

It is true that a multi-skilled technician costs more than a single skilled technician. This study argues that the total cost of completing a job may decrease as the maintenance system with MST will be more responsive and faster, which will save time and effort. To test this hypothesis, a maintenance system for Saudi Consolidated Electric Company (SCECO), a leading company in Saudi Arabia, was selected as a case study. The main focus is the head quarter maintenance division located at SCECO-East. This division is responsible for maintaining all administrative buildings, which consist of 30 buildings of various sizes and functions.

2. Methodology

Field surveys and interviews aimed at collecting data necessary for building two types of models: static and dynamic models. Static model, on one hand, is a two dimensional representation of the process by mapping it using flow chart techniques. A flow chart will show the logic, the activities and the decisions involved in performing maintenance work orders. On the other hand, dynamic model is referred to computer simulation where one can experiment the potentiality and limitation of certain concepts.

Out of the 60 employees working at the maintenance division, 23 were interviewed. The interviews were conducted in different phases to make sure that the collected information is accurate and to refine the maintenance process maps and the simulation model.

2.1 The Development of the SCECO Maintenance Process Map

The maintenance process is divided into two main sub-processes: 1) Preventive Maintenance (PM), and 2) Corrective Maintenance (CM) as shown in figure (1). The two sub-processes are interrelated where under certain conditions some preventive maintenance work orders are converted into corrective maintenance work orders.

Such maps played a role in visualizing the work process flow and made discussions with interviewees easy and fruitful. The author facilitated further discussions by asking the following questions, which were taken from Back and Bell (1994) and Al-Sudairi (2007):

- Which activity must be finished before the next activity can begin?
- Can this activity occur concurrently with any other activities?
- Which resources are required to perform these activities?
- What are the deliverables of these processes?
- How are the deliverables transmitted internally and externally?
- How often must certain activities be repeated?
- How long does it take to finish an activity? This is accomplished by having each interviewee give three time estimates for each task that he is responsible for (minimum, most likely, and maximum).
- What are the probabilities of decision outcomes?

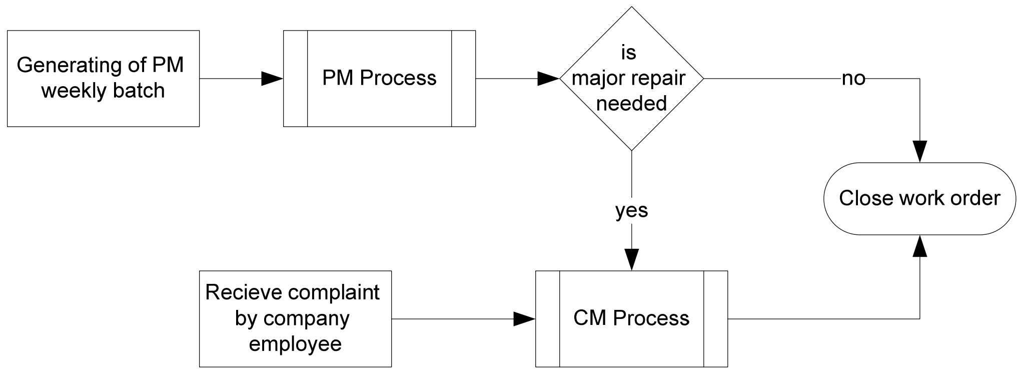


Fig. 1: Basic relationship between PM and CM processes.

Figure (1) shows the interrelationship between PM and CM processes at a macro level. However, figure (2) stipulates full details of activities and decisions of PM process. For detailed CM process, readers are advised to see the study of Alsudairi (2005).

PM work orders are generated in batches once a week. The PM engineer prepares the weekly batch, allocates work orders according to each maintenance unit, and submits work orders to each unit whereby they go through the normal PM process. There are five maintenance units under the Head Quarter of Maintenance Division. Each unit is responsible for operating a certain type of service. Under each unit there are several workshops that vary in size from one unit to another. In this study only units that are related to building maintenance are included. The selected units are: (1) Electrical Repair Unit (ERU), (2) Air Condition Repair Unit (ACRU), and (3) Facility Maintenance Unit (FMU).

The PM work orders are either closed after completion or transferred to the CM process. On the other hand, CM work orders enter the maintenance system by a request of a technician or a complaint from a customer. During the routine check, a technician who is performing PM work order can't continue the job because it requires major repairs. Thus, this PM work order will be converted into a CM work order or, in many cases, a CM dispatcher receives a complaint from a customer. This complaint will enter the maintenance system as a CM work order.

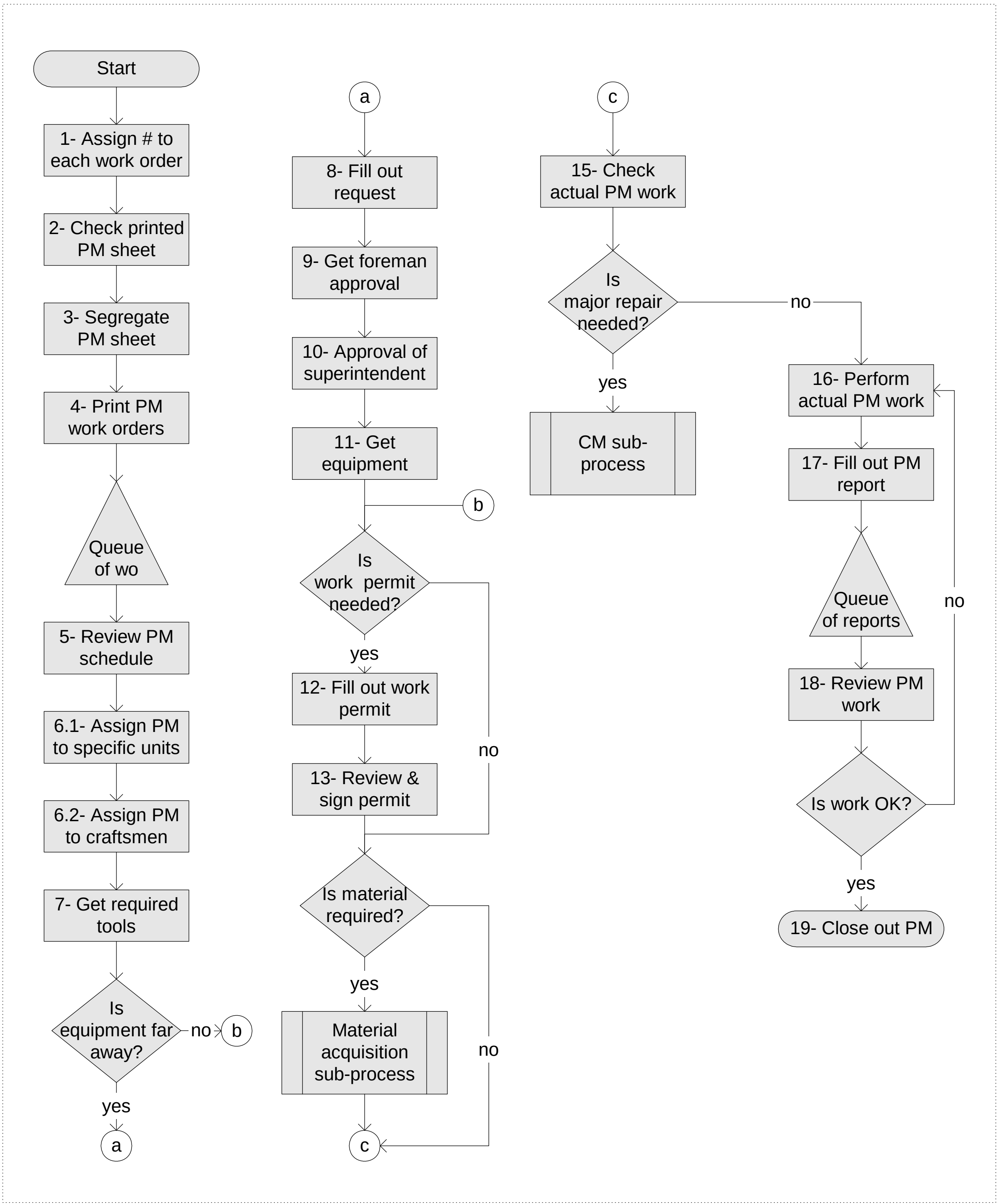


Fig. 2: Preventive maintenance detailed process map.

2.2 Collection of Quantitative Data

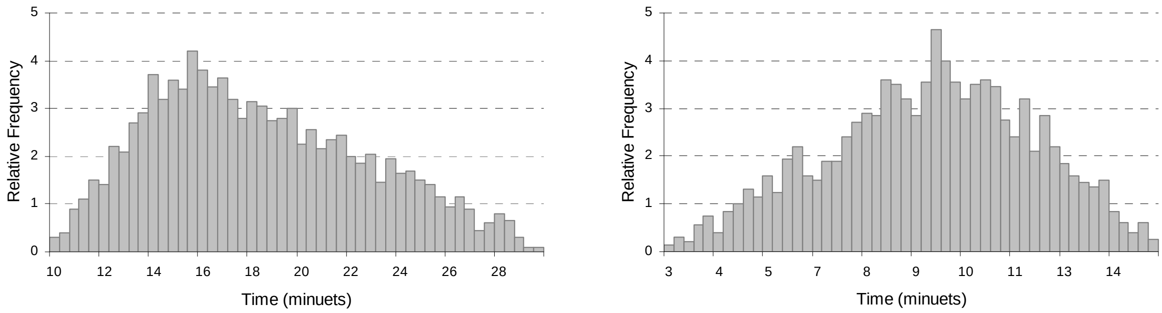
Measuring activities' durations is one of the critical inputs to the validity of simulation models. It is apparent from the process map presented in figure (2) that maintenance processes contain many activities. The activities' duration were estimated by experts who were asked to give three times (most likely, maximum, and minimum) for each activity in the PM process as shown in Tables (1). Quantitative data for CM activities can be found in the study of Alsudairi (2005). The sixth column in table (1) presents the average time for each activity that was calculated according to *Beta* distribution assumptions. The reason behind using *Beta* distribution is because of its adequacy and flexibility for most construction activities (AbouRizk *et al*. 1994 and Alkoc and Erbatur 1997). The average time was useful in constructing the initial simulation model for verification purposes. The three time estimates were entered for each activity in the simulation model. Figure 3 (a & b) shows an example of one PM activity and another CM activity in which Extend+BPR converts such estimates into distributions. The same procedure was done for all activities. According to Cassady *et al.* (2001) probability distributions of activities in simulation models ensure a more realistic portrayal of real systems.

Table 1: Time estimates in minutes of Preventive Maintenance activities.

No.	Task	Minimum	Most likely	Maximum	Average
1	Assign no. to each work order	5	8	12	8.17
2	Check printed PM sheet	4	8	10	7.67
3	Segregate PM sheet	2.5	4	7	4.25
4	Print PM work orders	5	10	15	10.00
5	Review PM schedule	3	7	11	7.00
6	Assign PM to specific units/craftsman	2	4	7	4.17
7	Get required tools	10	15	30	16.67
8	Fill out a request	10	15	30	16.67
9	Get foreman approval	10	18	25	17.83
10	Get approval of superintendent	11	20	30	20.17
11	Get equipment	10	15	30	16.67
12	Fill out a permit	30	45	60	45.00
13	Evaluate and sign permit	8	10	15	10.50
14	Material acquisition	3	30	90	35.50
15	Check actual PM work	10	11	15	11.50
16	Perform actual PM work	60	120	240	130.00
17	Fill out PM report	4	7	10	7.00
18	Review PM work	4	6	7	5.83
19	Close PM work order	2	3	4	3.00

Another important piece of information is the probability of occurrence of the decisions associated with both maintenance processes as shown in figure (2). For instance, a work permit is required whenever a WO is associated with hazardous equipment/material or it is located in a restricted area. To quantify this information, previous records of WOs were reviewed to find out the probability of each decision outcome by calculating the percentage of WO that needed work permits. This method of quantifying decisions is the one most used by several researchers (Hansen 1997, and Laguna and Marklund 2005).

With respect to maintenance work orders, it is also important to know whether they are preventive or corrective and to what maintenance unit they belong to. Figure (4) summarizes the type and percentages of maintenance WO for 52 weeks which indicates that most work orders are handled by ACRU (45% of PM WO) while FMU got the least (14% of PM WO). These percentages are useful in simulating the flow and type of WO. In fact, modern simulation packages are object-oriented. The object in this case is the maintenance work order whether preventive or corrective. Logic and issues related to the simulation model will be discussed in the next section.



(a) PM Activity # 11- *Get Equipment* distribution (b) CM Activity # 2- *Enter Complaint* distribution

Fig. 3: Two examples of activities' time distributions in both PM and CM processes.

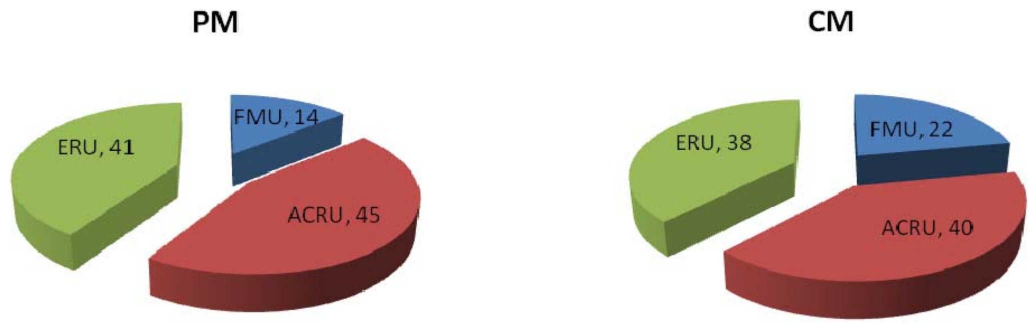


Fig. 4: Types and percentages of maintenance WOs.

Manpower cost is also another essential modeling input in order to compare the traditional system, which referred to as "as-is", with the proposed system, which referred to as "to-be". The cost of different technicians is gathered from SCECO personnel records. The cost of technicians varies according to their qualifications and years of experience. However, an average cost per hour was calculated so that it represents most technicians which is $15.2 per hour; on the other hand, the cost for a multi-skilled technician is $22.7 per hour (SCECO-Support-Facility 1999).

2.3 The Maintenance Simulation Model

To model maintenance processes, data collected in previous steps requires transfer into simulation notation. Each simulation package has its own form of activity notation or language (Back and Bell 1994). For this study, Extend+BPR was selected as the simulation modeling package because of its flexibility and adaptability in modeling lengthy complex processes (Krahl 2002).

Extend+BPR is an object-oriented simulation tool. In other literatures objects are referred to as "flow units" (Halpin and Riggs 1992). The word "flow" implies that objects are dynamic and as they move in a process they may change their attributes or may gain more. Knowing what and how of an object is very crucial in building a credible accurate simulation model.

Objects vary according to the system they belong to. Thus, the simulation models created for this study are designed to examine the flow of maintenance work orders for both PM and CM. This feature of object-oriented simulation packages allow the determination of how long each WO stays in a process that includes both processing time and waiting time. In doing so, one can accurately determine process efficiency.

Figure (5) shows a small portion of the maintenance model that was built on Extend+BPR. The most important part of any Extend+BPR model are the blocks, the libraries where blocks are stored, the dialogs associated with each block, the connectors on each block, and the connections between blocks (Krahl 2002). A block specifies an action or process; it is used to represent an activity, an event or a function of a model. Some blocks may simply represent sources of information. Others may modify information as it passes through them. Information comes into the block and is processed by the program that is embodied in the block. The block then transmits information out of the block to the next block in the simulation.

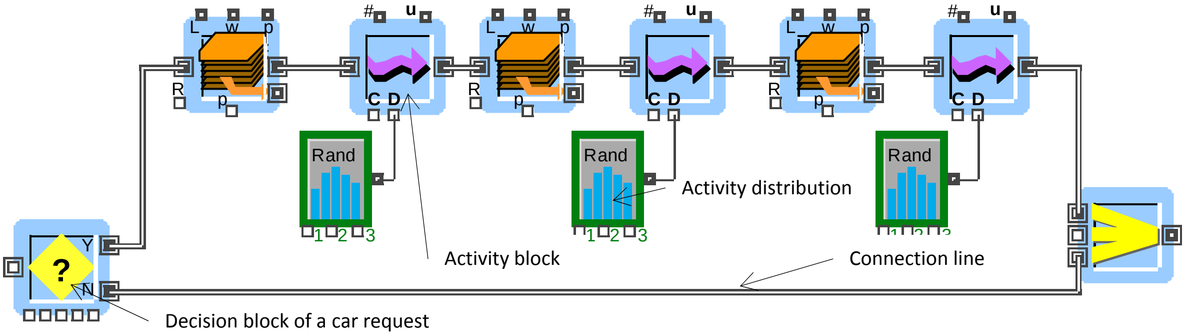


Fig. 5: Portion of the maintenance simulation model that mimics the car request activities.

A successful modeling is totally dependent on the development of a base-line model that accurately mimics the present work flow process and the interrelationships among various tasks (Ardhaldjian and Fahner 1994). Before experimenting with simulation to evaluate the effect of MST, it is necessary to validate the traditional model. A comparison between the model outcomes and the data gathered from both processes on site was made as shown in table (2) to ensure the validity of the model.

Table (2) shows two sets of data, actual and empirical, for the total cycle time to close out one work order of either PM or CM and the number of completed work orders per week. The actual data was gathered from previous records for both processes whereas empirical data was gathered from simulation models. Notice how close the two sets of data which proves that the simulation models are valid and ready for evaluation.

The validated "as-is" model was used as a reference point to measure and compare the impact of MST on maintenance processes. The concept of MST implied some changes to both PM and CM processes. By looking into the process map presented in figure (2), activities with numbers 3 (*Segregate PM sheets*), 6.1 (*Assign PM to specific unit*), and 6.2 (*Assign PM to* *craftsmen*) are not always required because the superintendent can most of the time assign work orders directly. Running the simulation model with these changes and being capable of meeting most maintenance orders due to MST, led to a leaner system that is going to be discussed further in the coming section.

Table 2: Comparing the outcomes of the as-is model with the actual data.

	Cycle Time (hours)		**Throughput (WO/week)**	
	Actual	**Empirical**	**Actual**	**Empirical**
PM	16	15	110	115
CM	22	20	80	76

3. Results Analysis

Table (3) compares results of both the "as-is" and the "to-be" maintenance models in terms of cycle time, labor cost, crew utilization and throughput. One may notice the remarkable improvement gained by implementing the concept of MST. Regarding the PM process, there is a 68% reduction in cycle time and 56% reduction in cost. In terms of crew utilization and throughput the PM process improved by 45% and 27%, respectively. Results with respect to the CM process are encouraging as well, but, they are less than those in the PM process. The difference in improvement is due to the fact that the maintenance policy in SCECO gave more priority to PM work orders. These improvements are attributed to the high response to work orders where they wait for a short time in the maintenance process. The role of the maintenance superintendent and the activities associated with him are markedly reduced in the "to-be" model.

Table 3: Comparing results of both the "as-is" and the "to-be" maintenance models.

	Cycle Time (hours)		**Labor Cost ($/WO)**		**Utilization**		**Throughput (WO/week)**	
	as-is	to-be	as-is	to-be	as-is	to-be	as-is	to-be
PM	15	4.8	295	129	42	87	110	140
CM	22	9.5	420	201	42	87	80	98

Figure (6) compares the crew utilization of the two simulation models where one can see the remarkable difference between the two. The ERU, ACRU and FMU curves belong to the utilization rate of the "as-is" model whereas the MST curve belongs the utilization rate of the "to-be" model. Almost 87% of the technician time in the "to-be" model is spent on performing maintenance work orders. One may notice how steady the "to-be" utilization curve is along the simulation run time; it has also gained a high rate of utilization right from the beginning as opposed to the "as-is" utilization curves. The utilization rate is the same in both processes, whether PM or CM, as all technicians are responsible for both types of work orders. The enhanced utilization of technicians contributed to the increase in throughput where 140 PM WO/week and 98 CM WO/week are accomplished. This is comparable to the results of Mjema study (2002) who found a 91% improvement of utilization rate.

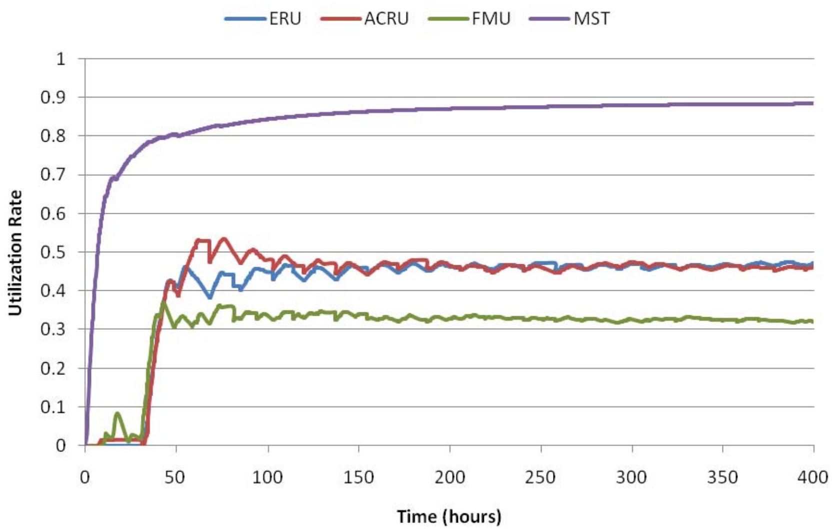


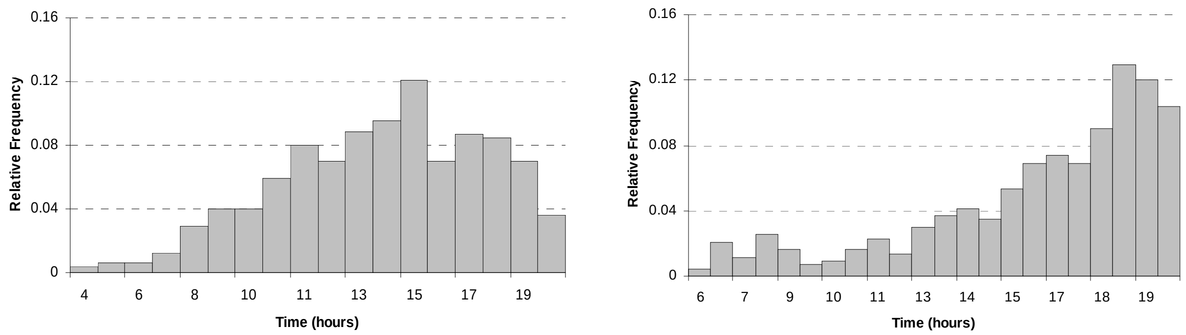
Figure 6: Comparison of technician utilization of the two simulation models.

On the contrary, crew utilization in the “as-is” maintenance process is very low. It is as low as 34% in facility maintenance unit (FMU) as shown in figure 6. This is because the work orders have to go through long paper work before they get assigned to a specific maintenance unit. Once these work orders reach their units, the superintendent checks the availability of his craftsmen who may be busy in other work orders. Another reason that led to low utilization is the type of work orders that may vary according to seasons. For instance, in summer there is more demand on A/C repairs and checkups than in winter. This necessitates a responsive and adaptable system that can meet most maintenance work orders. One way is to provide more skilled technicians who can handle most maintenance services.

Figures (7) and (8) present cycle time distribution of work orders for both PM and CM processes in the “as-is” and the “to-be” models. Again this shows the magnitude of the potentiality of MST. The work orders in the “as-is” system take longer to be completed where it takes an average of 15 hours compared to 4 hours in the “to-be” system. Besides, the long time of WO in the “as-is” system one may notice the huge variability in both distributions as shown in Figure (7). There is a 16-hour difference in the “as-is” preventive maintenance process, which is almost the same in the corrective maintenance process. The huge variability indicates a weakness in the existing process. In fact, Narayan (1998) concluded that process variability is a major source of cost increase, which is the case in the “as-is” process.

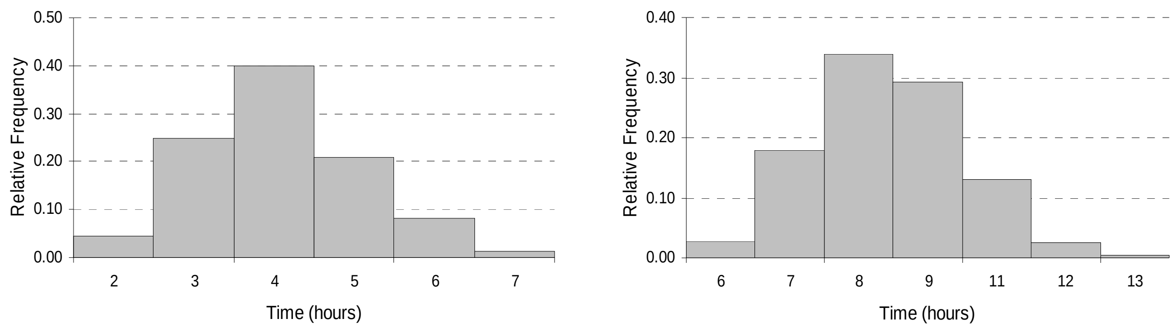
The number of multi-skilled technicians modeled in this study was almost one third the number of “as-is” technicians. This affirms another advantage of MST concept to the construction industry that is facing more demands and challenges to be faster and more productive, and to meet the shortage in skilled laborers. To overcome these demands and challenges, there is a need to invest more in training laborers in order to improve their skills in different services. This would enhance one major input, which is human resources, to construction/maintenance processes by adding more value to their outcomes and eventually to the final product or service.

The improvement gained by employing the concept of MST was relative to the “as-is” maintenance process practiced by SCECO, which contained huge amount of non-value adding activities. Looking back, figure 8 (a and b) shows that the “to-be” maintenance model has a better performance, but, work orders still go through variable time. It is not as variable as the ones in the “as-is” maintenance model. However, inefficiency still exists in the “to-be” model. This is because the emphasis of the current study is on multi-skilled technicians where the process stayed almost the same as in the “as-is” process.



(a) “as-is” PM cycle time distribution (b) “as-is” CM cycle time distribution

Fig. 7: Cycle time distribution for 2000 runs of the “as-is” maintenance process.



(a) “to-be” PM cycle time distribution (b) “to-be” CM cycle time distribution

Fig. 8: Cycle time distribution for 2000 runs of the “to-be” maintenance process.

Focusing on technologies also has a significant impact on leading to leaner processes. Many of the activities in the maintenance process of the case study can be done electronically. In doing so, some of the activities will be eliminated or the time needed to complete them is reduced which will expedite information transfer and enhance communication. For example, activities 8, 9 and 10 in the PM process can be mainly done electronically with minimal paper work, that is; work permits can be sent electronically to the superintend without the presence of a technician. While the technician awaits his superintendent’s approval, he can perform other work orders that will add value to the maintenance system. Indeed, integrating people, processes, and technologies is essential in adopting a system view of process management.

The presented case study is huge where there are many buildings of various functions and uses. The amount of maintenance work orders is expected to be huge and diverse as well. In situations like this, the MST concept may work well. In other situations where work orders are not as frequent/diverse as in this case study, an MST concept may not be very effective. The cost-benefit ratio of a multi-skilled technician may not be significant. This requires further investigation on the factors that influence the potentiality of MST.

4. Conclusion

This study evaluated the benefits of MST to a maintenance process of a leading company (SCECO) using object-oriented simulation package (Extend+BPR). Simulating the concept of MST led to significant improvement in terms of cycle time, labor cost, utilization and throughput. The average time and cost to complete one PM work order were reduced by 68% and 56%, respectively. Also, technician utilization and productivity improved by 45% and 27%, respectively. The performance of the PM process was better than that of the CM process because the former process was given more priority. Thus, the balance between the two processes requires more attention that may be achieved in future studies.

This study focused on people as one important aspect of process management. Extending maintenance technicians' breadth and depth of their skills will have a positive impact on their performance as well and eventually will add value to the final product or service. However, it is extremely important to look into maintenance processes as a system of different inputs that include people, materials and technologies in order to enhance their efficacy and value.

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